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ORIGINAL ARTICLE

Sacrum pubic incidence and sacrum pubic posterior angle: two morphologic radiological parameters in assessing pelvic sagittal alignment in human adults

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Abstract
Purpose The morphology and position of pelvis are critical in regulating the biomechanical organization of spine–pelvis–leg in the sagittal plane. Several radiological parameters have been developed to present the sagittal morphology of the pelvis such as pelvic incidence (PI) and Jackson's angle (PRS1). In addition, the femoral sacral posterior angle (FSPA) was developed for patients with a dome-shaped deformity in the upper plate of the sacrum. The identification of hip axis, which was represented by the line connecting the centers of femoral heads in normal subjects, was important for these parameters measurement. However, in subjects with fused hip joint or deformed femoral heads, the accurate localization of hip axis become imprecise. Herein, the upper edge of the pubic symphysis, which is easy to identify on the lateral X-ray film, was selected as an alternative landmark of the hip axis, and two morphologic parameters, the sacrum pubic incidence (SPI) and sacrum pubic posterior angle (SPPA), were proposed accordingly. The present study aimed to understand the reliability of these two parameters and their value in predicting PI, PRS1 and FSPA.
Methods Upright standing spine and pelvis radiographs of 60 normal adults (30 male and 30 female) with an average age of 38.5 years were obtained. Two independent observers then measured the following radiological parameters on the films: PI, PRS1, FSPA, SPI, SPPA, sacral slope, pelvic tilt and lumbar lordosis. The SPI is the angle between the line perpendicular to the superior plate of the first sacral vertebra at its midpoint and the line connecting this point to the upper edge of the pubic symphysis, while the SPPA is the angle between the line extending from the posterior upper edge of the sacrum to the upper edge of the pubic symphysis and the posterior side of the first sacral vertebral body. The intra-observer and inter-observer reliabilities of the parameters were analyzed using intraclass correlations. The correlations between parameters were analyzed by Pearson's correlation coefficients. Regression analysis was carried out to establish formulas to predict the values of PI, PRS1 and FSPA using the SPI and SPPA. A $p < 0.05$ was considered statistically significant.
Results The SPI was 64.4° ± 9.5° and 68.3° ± 9.4°, and the SPPA was 77.7° ± 7.5° and 78.7° ± 9.4° in males and females, respectively. These radiological parameters showed excellent intra- and inter-observer reliabilities, with an intraclass correlation >0.8. No gender differences were identified in these morphologic and positional radiological parameters. The SPI demonstrated strong correlation with PI and PRS1 ($R^2 > 0.9$, $p < 0.001$). In addition, strong correlation was also found between SPPA and FSPA ($R^2 > 0.9$, $p < 0.001$). Furthermore, both SPPA and FSPA showed close correlations with the other morphologic and positional parameters. Linear regression analysis established equations to predict PI and PRS1 using SPI and to predict FSPA by SPPA with significantly high reliability.
Conclusions Both SPI and SPPA are reliable parameters for determining the morphology of the pelvis. The SPI is precise in predicting PI and PRS1, while SPPA is reliable in predicting FSPA. The SPI and SPPA will allow further study on lateral spinal–pelvic alignment in patients with hip joint abnormalities.

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Keywords Sagittal alignment · Pelvic incidence · Sacral pubic incidence · Sacrum pubic posterior angle · Reliability

Introduction

The fully upright posture of humans significantly alters the loading forces on the spine, pelvis and lower leg. The pelvis tends toward verticalization in an attempt to couple lumbar lordosis and hip extension into a stable and ergonomic position to maintain postural equilibrium and spinal balance [1, 2]. In the past decade, several studies suggested that the understanding of sagittal pelvic alignment would benefit those exploring the mechanisms of and determining the treatment strategies for spinal diseases such as spondylolisthesis [3]. Several radiographic parameters have been proposed to represent the sagittal alignment of the pelvis and can be divided into two groups: positional and anatomic/morphologic parameters [4]. Positional parameters refer to horizontal or vertical lines and hence vary by position, while anatomic/morphologic parameters utilize reference lines related to the anatomy of the pelvis and thus remain constant regardless of the position and orientation of the subject [4].

Pelvic incidence (PI) was first described by Duval-Beaupere et al. [5] and is the most commonly used morphologic parameter describing the sagittal alignment of pelvis. In addition, Jackson et al. [6] expressed the pelvic sagittal shape in terms of "pelvic lordosis" (PRS1) while Legaye et al. [7] developed the femoro-sacral posterior angle (FSPA) to serve as an alternative morphologic pelvic parameter of PI in the case of a dome-shaped deformity of the sacrum. When measuring these parameters on a lateral view of the pelvis, it is critical to identify the hip axis, which was represented by the line connecting the centers of femoral heads in normal subjects, either by freehand [6] or with computer software [8], maintaining the assumption that the femoral heads are round in shape and located in the center of the hip joints. However, in patients suffering severe rheumatoid arthritis, ankylosing arthritis [9, 10] or necrosis in hip joint, an accurate estimation of the axis of the femoral heads is not possible.

In addition to the hip axis, the upper edge of the pubic symphysis has also been proposed as a key anatomic landmark of the anterior pelvic plane and used in assessing pelvic orientation [11, 12]. This identification of this edge is easy on the lateral X-ray film of pelvis and would not be affected by abnormalities of the femoral heads or acetabulum. Therefore, we hypothesized that the upper edge of the pubic symphysis can be an alternative anatomic point of the axis of the femoral heads to assess pelvic morphology in patients with hip abnormalities. Two new angular morphologic parameters, the sacrum pubic incidence (SPI) and sacrum pubic posterior angle (SPPA), were proposed by selecting the upper edge of the pubic symphysis instead of the center of the hip axis as one of the landmarks of the femoral head axis. In the present study, we analyzed the reliability of these two parameters and their correlation with established morphologic and positional parameters of sagittal pelvic alignment in asymptomatic adults, with the aim of determining alternative morphologic parameters of PI, PRS1 and FSPA in assessing sagittal pelvic alignment.

Materials and methods

Subjects

The study was approved by the Clinical Research Ethics Committee of the hospital. Asymptomatic adult volunteers were recruited into the study when they met the following inclusion criteria: (1) age between 20 and 65 years and (2) no history of trauma, spinal disease, history of spinal surgery or pain in the spine and lower extremity. Subjects then underwent physical examination and posteroanterior and lateral upright standing X-ray films. Subjects with any of the following conditions were excluded: (1) spinal deformities such as scoliosis, Scheuermann's disease or lumbar spondylolisthesis; (2) hip joint abnormalities, including necrosis of the femoral head, osteoarthritis, developmental dysplasia of hip; (3) lower limbs length discrepancy. Sixty subjects, including 30 males and 30 females, with an average age of 38.5 ± 10.9 years (range from 24 to 65 years), were recruited for radiographic analysis.

Radiography and image analysis

Each subject underwent a standing lateral radiograph of the spine and pelvis in the fist-on-clavicle position [8]. The following angular pelvic and spinal parameters (Fig. 1) were then measured using Surgimap (Nemaris Inc., NY, USA, version 1.2.1.82).

Sacrum pubic incidence (SPI): Value of the angle between the line perpendicular to the superior plate of the first sacral vertebra (S1) at its midpoint and the line connecting this point to the upper edge of the pubic symphysis.

Sacrum pubic posterior angle (SPPA): Value of the angle between the line extending from the posterior side of the upper edge of the sacrum to the upper edge of the pubic symphysis and the posterior side of the body of the first sacral vertebra.

Pelvic incidence (PI) [2]: Value of the angle between the line perpendicular to the superior plate of S1 at its midpoint

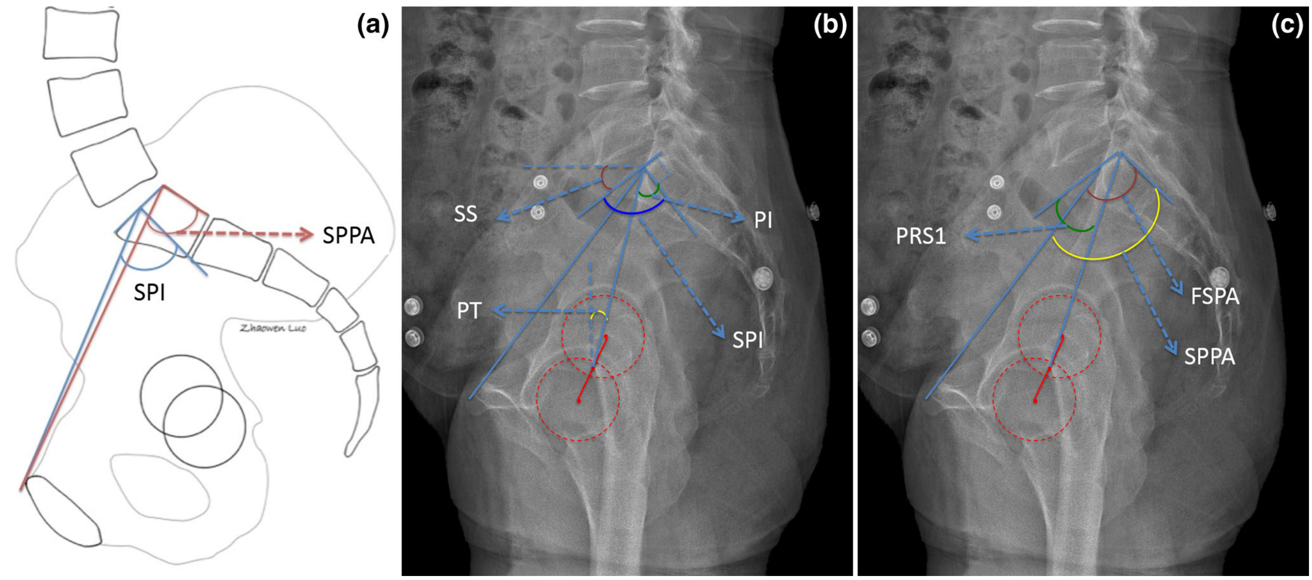

Fig. 1 Illustration of the radiological parameters of the pelvis on the sagittal plane. The parameters illustrated include sacral pelvic incidence (SPI), sacrum pubic posterior angle (SPPA), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), femoro-sacral posterior angle (FSPA), and pelvic lordosis or Jackson's angle (PRS1)

and the line connecting this point to the axis of the femoral heads.

Pelvic lordosis or Jackson's angle (PRS1) [6]: Value of the angle between the sacral superior plate and the line connecting the posterior point of the sacral plate to the femoral head axis.

Pelvic tilting (PT): Value of the angle between the vertical and the line connecting the midpoint of the sacral plate to the axis of the femoral heads.

Sacral slope (SS): Value of the angle between the superior plate of S1 and a horizontal line.

Lumbar lordosis (LL): Angle between the superior endplate of L1 and the superior endplate of S1.

Two authors (WJ Wang and MD Wu) independently and blindly performed the measurements to compare inter-observer reliability. In addition, these measurements were repeated by the first author (WJ Wang) after 4 weeks to compare intra-observer reliability.

Statistical analysis

Statistical data are presented as the mean ± standard deviation. The intra- and inter-observer reliabilities of the parameters were analyzed using intraclass correlations. Comparisons among males and females were carried out through Student's *t* test. In addition, the correlations between parameters were analyzed by Pearson's correlation coefficients. Regression analysis was carried out to establish formulas to predict the values of PI, PRS1 and FSPA using the two newly established anatomical parameters. A $p < 0.05$ was considered statistically significant.

Table 1 Gender differences in sagittal spinal–pelvic angular parameters (°)

	Male ($n = 30$)	Female ($n = 30$)	p value
PI	44.6 ± 9.0	46.9 ± 9.9	0.265
SPI	64.4 ± 9.5	68.3 ± 9.4	0.109
SPPA	77.7 ± 7.5	78.7 ± 9.4	0.68
PRS1	39.3 ± 8.0	37.0 ± 9.2	0.362
FSPA	58.6 ± 7.1	62.0 ± 8.7	0.104
PT	11.5 ± 7.0	12.5 ± 5.2	0.763
SS	32.9 ± 8.2	33.8 ± 8.3	0.679
LL	45.8 ± 11.7	49.9 ± 10.1	0.161

Comparisons were done by Student's *t* test

Results

The mean values and the standard deviations of the studied parameters in both males and females were summarized in Table 1. The SPI was 64.4° ± 9.5° and 68.3° ± 9.4°, and the SPPA was 77.7° ± 7.5° and 78.7° ± 9.4° in males and females, respectively. Statistical computation revealed no significant difference in the morphologic parameters (PI, PRS1, SPI, SPPA and FSPA) nor in the positional parameters (PT, SS, LL). Hence, these subjects were combined into one group for further analysis.

Reliability analysis showed high intra- and inter-observer agreements in the spinal-pelvic parameters, with intraclass correlations (ICC) >0.8 (Table 2). The intra-observer ICC were 0.987 and 0.872, and the inter-observer ICC were 0.943 and 0.852 in SPI and SPPA, respectively.

Table 2 Inter-observer reliability of manual measures

Parameters	Intra-observer reliability		Inter-observer reliability	
	Intraclass correlation	95 % confidence interval	Intraclass correlation	95 % confidence interval
PI	0.887	0.858–0.912	0.930	0.828–0.972
SPI	0.987	0.971–0.994	0.943	0.859–0.977
SPPA	0.872	0.835–0.914	0.852	0.613–0.941
PRS1	0.842	0.786–0.896	0.864	0.765–0.945
FSPA	0.852	0.749–0.914	0.801	0.509–0.919
PT	0.892	0.773–0.979	0.981	0.953–0.992
SS	0.813	0.704–0.931	0.953	0.883–0.981
LL	0.992	0.986–0.996	0.975	0.938–0.990

Additionally, both SPI and SPPA showed significant correlation with the other three morphologic parameters (PI, FSPA, PRS1) and positional parameters (PT, SS, LL) (Table 3). These results indicated that the two newly established parameters are reliable in representing the sagittal morphology of the pelvis. The correlations between the parameters are shown in Table 3.

It is interesting to note that the correlation coefficients (R^2) were >0.9 among PI, SPI and PRS1 as well as between SPPA and FSPA. Hence, by linear regression analysis using a stepwise model, SPI was shown to be a predictor of PI and PRS1 according to the equations PI = −20.522 + 0.999*SPI (R^2 linear = 0.918, $p < 10^{-6}$) and PRS1 = 95.883–0.884*SPI (R^2 linear = 0.847, $p < 10^{-6}$). Moreover, linear regression also showed that FSPA could be predicted using SPPA with the equation FSPA = −10.037 + 0.9*SPPA (R^2 linear = 0.892, $p < 0.001$).

Discussion

The importance of sagittal pelvic morphology is obvious in maintaining the spinal pelvic balance on sagittal plane and postural equilibrium in humans and in understanding the biomechanical pathogenesis of several spinal and pelvic diseases, such as lumbar spondylolisthesis [3, 13] and low back pain [11, 14]. The PI is an outstanding parameter in assessing the sagittal morphology of the pelvis [2, 4, 15] and in guiding surgical decision making [13]. An accurate assessment of PI relies on a clear identification of the superior endplate of S1 and the femoral heads on lateral X-ray films. However, in patients with severe rheumatoid arthritis, ankylosing arthritis in hip joint [9, 10], the femoral heads are in fusion with acetabulum, while in those with severe osteoarthritis or necrosis, the femoral heads are not round in shape. The pathologic changes lead to difficulty in identifying the femoral heads axis and measuring the PI. In a study which compared the pelvic inclination between normal hips and osteoarthritic hip, the upper edge of the symphysis pubis was selected as an anatomic landmark to connect to the promontorium to present the pelvic inclination by referring to the perpendicular line [11, 12]. To assess the sagittal morphology of the pelvis, the SPI and SPPA were proposed using the upper edge of the pubic symphysis as a landmark [11] instead of using the axis of the femoral heads in the present study. Both parameters showed high inter- and intra-observer reliability, significant correlation with other morphologic and positional parameters of the pelvis and high predictive values for PI, PRS1 and FSPA. These results supported our hypothesis that the SPI and SPPA could be reliable morphologic angular parameters of the pelvis on sagittal plane.

A strong correlation between PI and PRS1 has been reported by Legaye et al. [7] in a study of 72 male and 73 female normal adults (R^2 = 0.995). This high coefficient was thought to be due to the use of the upper plate of S1 to access both PI and PRS1 [7]. The present study also showed a strong correlation between PI and PRS1 (R^2 = 0.967). Moreover, a strong correlation was also found between SPI and PI (R^2 = 0.958) and between SPI and PRS1 (R^2 = −0.920). Both SPI and PI use the line perpendicular to the superior plate of S1 at its midpoint as one side and the midpoint as the endpoint of the angles. Similarly, both SPI and PRS1 use the same endpoint (the posterior side of the upper edge of the sacrum), and one side of SPI is perpendicular to one side of PRS1 (the superior plate of S1). With these strong correlations, SPI was supposed to serve as the predictor of PI and PRS1

Table 3 Pearson's correlation coefficients between morphologic parameters in asymptomatic adults (** $p < 0.01$)

	PI	SPI	SPPA	PRS1	FSPA	PT	SS
SPI	0.958**						
SPPA	0.632**	0.709**					
PRS1	−0.967**	−0.920**	−0.569**				
FSPA	0.712**	0.717**	0.945**	−0.681**			
PT	0.566**	0.477**	0.377**	−0.602**	0.522**		
SS	0.705**	0.733**	0.429**	−0.636**	0.396**	−0.182	
LL	0.637**	0.644**	0.367**	−0.597**	0.370**	−0.095	0.842**

when the exact axis of the femoral heads is not available. This hypothesis was supported by linear regression analysis using a stepwise model, which established two formulas to calculate the PI and PRS1 using SPI with high reliability (93.4 % for PI and 87.5 % for PRS1).

In subjects with a flat upper sacral end plate, the measurements of PI and PRS1 are straightforward, with high intra-observer and inter-observer reliability [16, 17]. However, the measurement would be imprecise in cases of a dome-shaped deformity of the end plate [7, 18]. In these subjects, the FSPA was proposed to represent the pelvic morphology by Legaye et al. [7] and showed good inter-observer reliability and high correlation with PI ($r = 0.8475$) and PRS1 ($r = 0.8424$). In agreement with that finding, FSPA also showed good correlation with both PI and PRS1 in our study. Furthermore, the highest correlation was found between FSPA and SPPA due to using the posterior side of the S1 body as the same side and the posterior point of the S1 superior end plate as the endpoint of the angles. Nevertheless, both parameters showed the same correlations with other morphologic and positional parameters of the pelvis. Hence, an equation for predicting FSPA using SPPA was also computed by regression analysis with an accuracy of 89.2 % in the present study. This equation would be helpful in understanding the pelvic morphology in subjects who have suffered both hip abnormalities and spondylolysis with high-grade listhesis.

The sagittal alignment of spine and pelvis in patients suffering developmental dysplasia of hip (DDH) has been reported [19, 20]. However, in these patients the femoral heads are dislocated but not in the center of acetabulum, and the PI measured according to the definition and cannot be used to represent the sagittal morphology of pelvis. Hence the comparisons on the sagittal morphology of pelvis between DDH with other subjects are not available. Results of the present study suggested that the SPI could be an alternative parameter to show the sagittal morphology of pelvis in patients with DDH. More interestingly, when the abnormalities of hip were corrected, i.e., by hip arthorplasty or osteotomies [21], the estimated PI by SPI could be used to assess the accuracy of the restoration of hip axis.

Both angular and distance parameters should be used to present the morphology of the pelvis and to calculate equations predicting PI, PRS1 and FSPA. In the present study, distance parameters, such as the thickness and radius of the pelvis, were not used for analysis due to the concern regarding lower reliabilities in these measurements [22]. The lack of distance parameters would reduce the accuracy of the predictive value of SPI and SPPA for PI, PRS1 and FSPA. Several studies have reported the absolute values of these parameters and showed low variation among subjects [4]. In addition, high correlations were shown between SPI and PI, PRS1, and between SPPA and FSPA ($R^2 > 0.9$), suggesting that the effect of pelvic thickness might not be critical and may help in understanding the high reliability of these equations established in the present study.

In conclusion, two new morphologic parameters were proposed to represent the morphology of the pelvis in asymptomatic adult. They showed high inter-observer reliability and significant correlation with the other morphologic and some other positional parameters, suggesting that the two parameters are interdependent parameters of current sagittal spinal pelvic parameters. Furthermore, the PI and PRS1 could be predicted using SPI, while FSPA could be predicted using SPPA with high reliability.

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Conflict of interest None.

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